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ON THE VELOCITY STRUCTURE OF THE INTERSTELLAR CLOUDS NEAR RHO OPHIUCHI

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ABSTRACT

Accurate radial velocities of the optical interstellar features for some of the B stars embedded in the ρ Oph complex are obtained by averaging results of several photographic high-dispersion spectra. In at least one case, there is a real difference between the radial velocity of the atomic features (Na I and Ca II) and the molecular ones (CH and CN). We show that it is probable that the CH and CN are concentrated either in a separate cloud (i.e., region of space) from the Ca II and Na I or in a cloud whose outer parts are expanding rather than in a single cloud which is contracting or rotating.

Subject headings: interstellar matter — nebulae

I. INTRODUCTION

In the interpretation of interstellar lines of various atomic and molecular species, one is often forced to assume that all the lines observed in a given direction are formed in the same region of space. Several recent investigations have questioned this assumption. Cohen (1973) has presented evidence based on equivalent widths that the atomic interstellar lines are preferentially formed in the less dense regions of the interstellar medium, while CH is associated with dense clouds. On the basis of the line widths Heiles (1973*a*) has suggested that emission lines of NH_3, CS, and CH_3OH are formed preferentially in regions of different densities within the Sgr B2 and Ori A clouds. Hobbs (1973) has observed the interstellar lines in ζ Oph with an interferometer, and finds that the CH^+ line has a radial velocity (V_r) +1.8 km s^{-1} larger than the atomic lines, but is unable to decide whether the two regions of formation of the lines are at the same position in the line of sight.

The ρ Oph region, which is dense, extensive, and with many embedded stars, seems to be an ideal case to establish whether different interstellar lines are formed in coincident regions of space. A map of the region is given by Heiles (1968), and several photographs are shown by Carrasco, Strom, and Strom (1973).

II. MEASUREMENTS

For the optical interstellar velocities, we give our results for stars embedded in the ρ Oph complex in table 1. The spectra were taken with the 100-inch (2.5-m) telescope at Mount Wilson Observatory and the 60-inch (1.5-m) telescope at Cerro Tololo Inter-American Observatory by J. Cohen and G. Wallerstein separately. Each author measured his own spectra, and the results were averaged to give the entries in table 1. The accuracy of the entries is expected to be ±1 km s^{-1} where at least three spectra were averaged,

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TABLE 1

VELOCITIES FROM OPTICAL INTERSTELLAR LINES

Star	E_{B-V}	Velocity (km s^{-1}) Na I	Ca II	CH (4300.321)	CN	Number of Spectra Na I	Ca II	CH	CN
ρ Oph A	0.47	−8.6	−7.8(−8.2)	−6.2(−8.8)	...	4(18)	2(9), 1(4.5)	2(9), 1(4.5)	...
ρ Oph B	0.47	−9.2	−8.0(−8.3)	−9.3(−8.2)	...	3(18)	1(9), 1(4.5)	1(9)	...
HD 147888	0.53	−12.9	−8.5(−8.0)	−7.5	...	1(18)	3(9), 1(4.5)	1(4.5)	...
ρ Oph C	...	−10.8	−10.0	...	...	1(18)	2(9) ...	...	...
HD 147889	1.08	−10.8	−9.7	−4.8	−5.4	1(18)	3(9) ...	3(9)	1(9)
HD 147701	0.72	...	−4.0	−2.0	...	...	2(9) ...	2(9)	...

NOTE.—Velocities in parentheses are from Adams (1949) as corrected by Routly and Spitzer (1952).

TABLE 2

VELOCITIES FROM INTERSTELLAR RADIO LINES

Molecule	V_r (km s^{-1})	σ_V (km s^{-1})	Source	$V_\odot$
H_2CO (absorption, unsaturated)	3.4	1.2	Dieter (1973)	−7.0
	3.8–4.0		Heiles (1973b)	−6.6 to −6.4
CO (emission, saturated)	3.4	3.1	Encrenaz (1973)	−7.0
OH (emission)	+3.7	1.4	Heiles (1968)	−6.7
H I	2.8–4.5	...	Knapp (1973)	−5.9 to −7.6

± 2 km s^{-1} where only two spectra were available. We also show in table 1 the values of V_r given by Adams (1949) as corrected by Routly and Spitzer (1952). The mean difference in velocity between CH and the atomic lines (giving Ca II double weight, since we have more measurements and higher dispersion than for Na I) is 2.6 km s^{-1}. The most heavily reddened star, HD 147889, has the largest difference in velocity. The CH velocity for HD 147889 is confirmed by one measurement of the surprisingly strong CN line at λ3874A. The CH velocity for ρ Oph B is very uncertain since the line was not measurable on a plate of 4.5 Å mm^{-1}. Omitting ρ Oph B yields a mean CH velocity of -5.5 km s^{-1} and a difference between CH and atomic lines of 3.0 km s^{-1}.

Measurements of V_r and the full width at half-maximum of the lines in velocity space (σ_v) are given in table 2 for the radio observations of interstellar molecules in the ρ Oph region. The final column removes the correction to the local standard of rest so as to facilitate comparison with optical data. The exact form of the correction used by the Berkeley group was kindly supplied by Dr. N. Dieter. We note that the velocities of the radio region lines fall closer to the CH velocities.

A similar attempt to detect V_r differences in the Perseus OB2 region using ο Per, ζ Per, and ξ Per failed, as for a given star the maximum difference in V_r over all the optical interstellar lines (including CH, CH^+, and CN) was 2 km s^{-1}. Since the Perseus cloud is less dense and these stars are only in the periphery of the cloud ($E_{B-V} < 0.4$ mag), we are not surprised by the failure to see variations in V_r. However, the observations confirm our laboratory wavelength for the CH line.

III. INTERPRETATION

We now seek to explain the differences in the measured values of V_r for different lines and different stars. If we wish to assert that all the observed features are formed in the same cloud, then the cloud must be either rotating or collapsing. Rotation large enough to explain the 3 km s^{-1} discrepancy seems to be eliminated by the uniformity of V_r in the CO map presented by Penzias *et al.* (1972). One might then argue that the entire cloud is collapsing, with the outermost thin parts (where the atomic interstellar lines are formed) being relatively stable, and the inner, more dense regions where the molecules predominate, collapsing. The observed discrepancies of V_r are similar in size to those calculated theoretically by Disney, McNally, and Wright (1969). However, the details fail to fit exactly. The radio lines (observed in emission from the near part of the cloud) which are formed in regions more dense than CH, should have a V_r less negative than CH. Since the H_2CO is unsaturated (hence, formed over the nearer and farther part of the cloud), it should have a larger velocity dispersion than is observed by Dieter (1973). We are left with the conclusion that there are two clouds involved. The northern one, including ρ Oph and reaching to HD 147889, has a V_r of -8 km s^{-1} and interstellar lines of Ca II, Na I, and perhaps weak CH^+. The denser cloud, which extends from near HD 147889 south, has H_2CO, OH, strong CH, and weak atomic features in its less dense regions (the southern edge near HD 147701).

The existence of two physically unrelated clouds in close proximity at $b = +17°$ seems somewhat unlikely. The remaining possibility is that the inner, dense regions of the cloud are relatively stable and the outer thin regions are expanding away from the cloud center. Since we see optical interstellar lines from only the near part of the cloud, there is no conflict with either the optical or the radio data. This picture is supported by unpublished radio observations by Encrenaz and also by Strom, Grasdalen, and Strom (1974).

The discrepancies between V_r for different species in the same star (HD 147889) are well established. We have argued that these arise from either two separate clouds or one cloud whose outer low-density regions are expanding. The less dense regions give rise to largely atomic interstellar lines; the denser ones, with a V_r of about $+3$ km s^{-1} relative to it, to molecular interstellar lines. We await with interest radio maps in H_2CO and OH for this region as well as the observation of interstellar lines with the *Copernicus* satellite.

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